

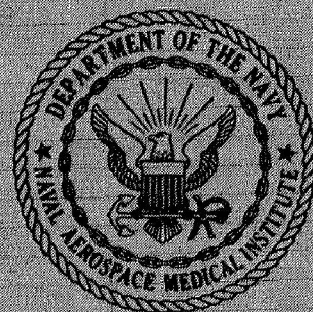
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PARABOLIC FLIGHT BY CORIOLIS ACCELERATIONS

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SUMMARY PAGE

THE PROBLEM

The purpose of the present study was to demonstrate the susceptibility of human subjects to motion sickness when exposed to Coriolis accelerations in the weightless phase of parabolic flight. To accomplish this purpose two major requirements had to be met. First, the stimulus, Coriolis accelerations, had to be confined to the brief period of weightlessness in a parabolic flight maneuver, and, second, it was essential to include subjects with a history of unsusceptibility to motion sickness in standard parabolic flights.

FINDINGS

Nineteen normal persons and three deaf subjects with bilateral loss of labyrinthine function (L-D subjects) were exposed to Coriolis accelerations during the brief periods of weightlessness in parabolic flight by having them move their heads while rotating in a Bárány chair at 30 rpm. None of the L-D but all of the normal subjects except three experienced motion sickness: Only one of eight subjects selected on the basis of insusceptibility to symptoms in standard parabolic flights was free of symptoms; the other seven were motion sick and completed on the average only six parabolas. Two of three subjects selected primarily on the basis of low susceptibility to Coriolis acceleration in a slow rotation room were symptom free, and one was motion sick but his level of symptoms did not reach the end point of severe malaise during ten parabolas. In addition to demonstrating susceptibility to motion sickness when exposed to Coriolis acceleration in the weightless phase of parabolic flight, the findings are important in emphasizing the difficulty in predicting susceptibility to motion sickness in novel force environments.

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INTRODUCTION

In a previous experiment dealing with motion sickness in parabolic flight (9) six persons with bilateral labyrinthine defects (L-D subjects) and nineteen naive normal subjects not selected on the basis of susceptibility to motion sickness were the participants. The L-D subjects completed the "required" 40 parabolas without experiencing symptoms of motion sickness. Five of the normal subjects failed to complete the 40 maneuvers, and only two of the remaining fourteen were symptom free. The obvious conclusion was reached that parabolic flight is an effective stressor, and it was tentatively concluded that "if weightlessness is a factor in precipitating symptoms of motion sickness, it is not a strong factor." The problem has been reviewed by a number of authors (1,2,4,7,8,10,13) without much change in that opinion.

The purpose of the present study was to demonstrate the susceptibility of human subjects to motion sickness when exposed to Coriolis accelerations in the weightless phase of parabolic flight. To accomplish this purpose two major requirements had to be met. First, the stimulus, Coriolis accelerations, had to be confined to the brief period of weightlessness in a parabolic flight maneuver, and, second, it was essential to include subjects with a history of unsusceptibility to motion sickness in standard parabolic flights.

PROCEDURE

SUBJECTS AND THEIR EVALUATION

Three L-D subjects and twenty-one normal persons participated. All subjects were in good health and all had met the medical and operational requirements for participation in zero-g flights. The L-D subjects, 22 to 27 years of age, had acquired their defects as a consequence of meningitis at an early age. The twenty-one normal subjects, twenty men and one woman (subject number 15), ranged in age from 19 to 46 years. Three of them were selected because of low susceptibility to symptoms when exposed to Coriolis accelerations in the slow rotation room (SRR), while eight were selected because of unsusceptibility to symptoms during standard parabolic flights. All twenty-one had normal hearing except one who, unaccountably, demonstrated in the audiogram a very slight "conductive loss" in the range of 4000 cps. The "threshold caloric test" (11) was conducted in thirteen, and all values were within the normal range. Ocular counterrolling (12) was tested in six and the values were normal.

DEVICES

The flights were made in a jet aircraft (KC-135) specifically modified and staffed for experimentation under conditions of weightlessness (3). A typical maneuver, termed a parabola, consisted of a shallow dive followed by a pull-up generating approximately 2.0 g and a push-over into a ballistic trajectory with a period of near-weightlessness lasting 24 to 28 seconds; recovery involved a pull-out generating about

2.0 g followed by level flight. Unless interrupted, a flight sequence consisted of 20 to 40 parabolas.

Mounted in the cabin was a motor-driven Bárány chair modified for use in the KC-135. The subject was restrained in the chair by shoulder harness and seat belt. The experimental area was shielded from the cabin lights by means of curtains. Facilities were available for voice communication between experimenter and pilot.

THE CORIOLIS ACCELERATIONS

With the subject seated on the chair Coriolis accelerations were generated by his active head motions while the chair rotated at 30 rpm. These head motions were made in the frontal and saggital planes at a rate of about one every two seconds; a "motion" consisted of a rotation away from and return to the upright. The head rotated about 45° right and left, somewhat further forward, and somewhat less backward. These accelerations constitute a bizarre stimulus pattern to the semicircular canals similar to, if not identical with, that generated in a ground-based laboratory.

The otolith organs were also stimulated in a bizarre manner while the subject rotated at 30 rpm in weightlessness. With head upright, the centripetal force was approximately 0.05-g unit directed horizontally but in opposite sense to the two organs. If the center of the head was displaced 6 inches leftward or rightward from the center of rotation at the extreme flexed position, the vectors representing forces acting on the two labyrinths at different radii would have the same sense, but different magnitudes, approximately 0.1-g and 0.2-g unit, respectively. On moving the head forward and backward the two labyrinths would be equally distant from the center of rotation. At uniform velocity between the upright and flexed position the direction of the Coriolis acceleration vector would be normal to the directions of the other two vectors, and the magnitude approximately 0.04-g unit.

METHOD

The general procedure was to expose each subject to Coriolis accelerations during the weightless period in ten successive parabolas unless the endpoint "severe malaise" supervened. This meant taking along the number of subjects necessary for testing during a complete flight sequence of 20 to 40 parabolas. There was considerable opportunity to observe the effects of parabolic flight both before and after exposure to Coriolis accelerations. During flight, when the signal was received that zero-g condition prevailed, the chair was set in rotation at 30 rpm and the subject, with eyes open, began the head movements. This was continued until the signal was given that the weightless period was about to end. The number of head movements were not counted, but around ten were made at 30 rpm and a few at slower velocities during each parabola.

The severity of motion sickness was graded according to diagnostic criteria described elsewhere in detail (5): slight, moderate, or severe malaise (M I to III), frank sickness (S), and vomiting (V).

Between parabolas the experimenter took the opportunity to observe the subject under lighted conditions and, following termination of the flight, both experimenter and subject filled out questionnaires designed to catalogue and quantify the subjective and objective symptomatology.

RESULTS

The results are summarized in Table I. Among the normals, subjects number 1 and number 2 became sick during a standard parabolic flight and consequently were not exposed to Coriolis accelerations. Subject 16 deserves special mention. He had never been motion sick as an aviator (> 1200 hours) and had frequently experienced zero g in small aircraft but not in parabolic flight. While exposed to Coriolis accelerations during the fourth parabola, he vomited. A postflight check revealed that, unknown to him, he had a slight fever, and subsequently he experienced a gastrointestinal "disturbance." Six days later he was fit, and the experiment was repeated. He had no concern over the outcome and completed ten parabolas without symptoms of motion sickness. This was a dramatic difference in response and a dramatic demonstration of the significance of lack of fitness due to a mild gastrointestinal disorder. Among the eight with much experience in standard parabolic flight and virtual immunity to motion sickness, three vomited, two were frankly sick, and one experienced severe malaise; at the end of ten parabolas the symptoms of one had not reached the endpoint, but he experienced moderate malaise; the remaining subject was symptom free. Two of the three subjects selected because of low susceptibility to motion sickness in the SRR were symptom free, while the third experienced only moderate malaise. Of the other seven normal subjects, three experienced nausea and vomiting, two were frankly sick, and one had severe and one moderate malaise.

None of the three L-D subjects experienced motion sickness and two enjoyed the flights, taking every opportunity to go aboard. The third, at the time of flight, was experiencing a gastrointestinal disturbance, and it is noteworthy that although he was sometimes "dizzy" on pull-outs and, later, was "faint" when blood was drawn, he did not experience motion sickness.

DISCUSSION

The vestibular organs are affected quite differently in weightlessness. At rest there is physiological deafferentation of the otolith apparatus, but there is no corresponding effect on the semicircular canals. There is some evidence that lifting the gravitational stimulus to the otolith receptors would leave them with a resting discharge (6), and presumably receptors in the canals would not lose their spontaneous activity. With natural movements of the body (head) the angular accelerations generated would provide a stimulus to the canals much the same as under terrestrial conditions, but the transient linear accelerations might or might not constitute an adequate stimulus to the otolith apparatus, and, if adequate, the information would not be useful for orientation to the upright.

Table I
Vital Statistics and Summary of Findings in 24 Subjects

Subjects		History of Motion Sickness				Susceptibility to Coriolis Acceleration in g-Zero		
		Work Status	Aircraft		Standard Parabolic Flight		Phase of Parabolic Flight	
No.	Age		Exposure *	M/S	Exposure	M/S	No. of Parab.	Severity of Motion Sickness**
1	31	Aviator	>Ad.	Occ.	0		0	
2	25	M. D.	Ad.	Occ.	Ad.	Occ.	0	
3	26	Civ.	>Ad.	Never	>Ad.	Once	10	S (V)
4	31	Capt. USAF	>Ad.	Occ.	>Ad.	1st Fl.	3	S (V)
5	22	Civ.	>Ad.	Never	>Ad.	Rarely	10	M II
6	30	Aviator	>Ad.	Never	>Ad.	Twice	6	M III
7	22	Lt. USAF	>Ad.	Occ.	>Ad.	1st Fl.	10	Nil
8	38	Aviator	>Ad.	Twice	>Ad.	Never	4	S (V)
9	46	Sgt. USAF	>Ad.	Rarely	>Ad.	Only during gymnastics	5	S
10	26	Lt. USAF	>Ad.	Only acrobat.	>Ad.	Once	5	S
11	19	Enl. USN +	>Ad.	Twice	Ad.	Never	10	Nil
12	26	Enl. USN +	>Ad.	Rare	Ad.	M II 1st Fl.	10	M II
13	19	Enl. USN +	<Ad.	Never	Ad.	Never	7	Nil
14	28	Aviator	>Ad.	Rarely	<Ad.	Never	4	S (V)
15	34	Capt. USAF	Ad.	Occ.	<Ad.	Never	1	S (V)
16	32	Aviator	>Ad.	Never	<Ad.	Never	1st trial 4 2nd trial 10	S (V) Nil
17	27	Lt. USN	>Ad.	Many times in turb.	0		10	M II
18	34	Aviator	>Ad.	Occ.	0		1	S (V)
19	29	Lt. USN	Ad.	Occ.	0		4	M III
20	25	Aviator	>Ad.	Rare	0		2	S
21	38	Capt. USAF	Ad.	Once	0		3	S
22	26	Civ. ‡	>Ad.	Never	0		10	Nil
23	23	Civ. ‡	>Ad.	Never	Ad.	Never	10	Nil; dizzy on pull-out
24	23	Civ. ‡	>Ad.	Never	Ad.	Never	10	Nil

*Adequate; > Ad.; < Ad.

** S - frank motion sick; V vomit.

M - Malaise I slight II moderate III severe

+ Slow Rotation Room

‡ Bilateral loss labyrinthine function.

In the present experiment the Coriolis accelerations generated while the subject was rotating at 30 rpm constituted a strong unusual stimulus to the semicircular canals, similar if not identical to that generated by the same rotations in the laboratory. On the other hand, the forces acting on the otolith apparatus were dramatically different from those acting in the presence of gravity. Under terrestrial conditions the inertial forces would sum with gravity and, while continually modifying the resultant vector, would do so within a maximal change in angle of approximately 15° . In weightlessness, although the maximal linear forces are reduced in magnitude by about four-fifths, not only is this more than a thousandfold above threshold but also the pattern is extremely bizarre and meaningless in terms of a normal behavioral response. In short, the g-loading was far less but the pattern more unusual than on Earth.

Although this limited experimental probe did not offer much of an opportunity to evaluate the individual roles of the canals and otoliths in causing motion sickness, the salient fact stands out that the L-D subjects, as expected, did not experience symptoms while the majority of the normal subjects were sick. If one excludes the three subjects selected on the basis of low susceptibility to Coriolis accelerations in the SRR, then only one normal person (subject 7) was symptom free, and another (subject 16) had symptoms when ill but not after recovery.

The findings in this experiment have limited relevance to the stressful accelerations which might be generated in a spacecraft rotating at low velocities. It was clearly demonstrated, however, that familiarity with and insusceptibility to motion sickness in standard parabolic flight were not important determinants in predicting whether a person would experience symptoms when exposed to Coriolis accelerations. On the other hand, there was an indication that susceptibility to symptoms in the SRR correlated with susceptibility in the Bárány chair under the conditions of this experiment.

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